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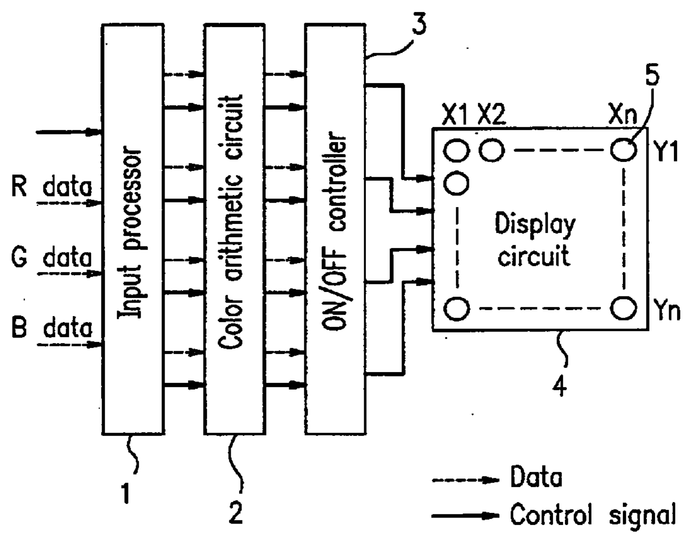
(54) Colour display using LEDs

(57) A display device includes: a light-emitting block including a plurality of light-emitting elements for emitting N number of different basic colors; an input circuit for receiving an input data representing a first color, a second color and a third color; a converter for converting the input data into an output data representing N number of basic colors; and a controller for controlling ON/OFF states of the plurality of light-emitting elements according to the output data. N is an integer of 4 or higher.

FIG. 1



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Description

BACKGROUND OF THE INVENTION

1. FIELD OF THE INVENTION:

The present invention relates to a light-emitting diode display device (hereinafter, simply referred to as an "LED display device") having a display area where a plurality of light-emitting blocks, each corresponding to one dot, are arranged in a matrix.

2. DESCRIPTION OF THE RELATED ART:

In order to obtain an LED display device capable of displaying a plurality of colors so as to realize, for example, a full-color display or a multi-color display, each of light-emitting blocks, which corresponds to one dot of the LED display device, needs to emit at least light of three basic colors, namely, red (R), green (G) and blue (B) light.

In a conventional LED display device, the light-emitting blocks each include three light-emitting diodes (hereinafter, simply referred to as "LEDs") corresponding to **R** signals, **G** signals and **B** signals, respectively. Each of such LEDs is associated with an input processor for receiving one of the **RGB** signals, a color arithmetic circuit for adjusting colors and an ON/OFF controller for controlling the ON/OFF state of a display circuit. In other words, the conventional LED display device includes LEDs each having a three-unit structure corresponding to the **RGB** signals.

However, conventional LEDs have insufficient light-emitting characteristics for displaying a color close to a pure (monochromatic) green color. Therefore, each light-emitting block is formed to consist of a red LED, a blue LED and a yellow-green LED, where the yellow-green LED is driven by the input processor, the color arithmetic circuit and the ON/OFF controller such as to emit light having a color closer to a pure green color.

Although red and blue colors obtained by such a conventional LED display device can stand comparison with those obtained in a television, a CRT or the like, color reproducibility of the conventional LED is poor in a green color region.

In theory, it is possible to produce a green LED capable of emitting pure green light. However, this would involve a large amount of cost and trouble.

SUMMARY OF THE INVENTION

According to one aspect of the present invention, a display device includes: a light-emitting block including a plurality of light-emitting elements for emitting N number of different basic colors; an input circuit for receiving an input data representing a first color, a second color and a third color; a converter for converting the input data into an output data representing N number of basic colors; and a controller for controlling ON/OFF states of the plurality of light-emitting elements according to the output data. N is an integer of 4 or higher.

In one embodiment of the present invention, a color production region of the light-emitting block on a chromaticity diagram has a plurality of regions defined by M number of reference colors. Each of the M number of reference colors are obtained based on at least one of the N number of basic colors. The converter includes a circuit for selecting one of the plurality of regions in accordance with the input data and a circuit for generating the output data based on at least one of the reference colors corresponding to the selected region.

In another embodiment of the present invention, the plurality of regions covers a color production region of a CRT.

In still another embodiment of the present invention, at least one of the M number of reference colors is different from the N number of basic colors.

In yet another embodiment of the present invention, the N number of light-emitting elements are four light-emitting diodes which emit light of the basic colors, namely, red, blue, yellow-green and blue-green, respectively.

In still another embodiment of the present invention, M is an integer of 4 or higher.

Thus, the invention described herein makes possible the advantages of providing an LED display device having enhanced color reproducibility in a green color region.

This and other advantages of the present invention will become apparent to those skilled in the art upon reading and understanding the following detailed description with reference to the accompanying figures.

BRIEF DESCRIPTION OF THE DRAWINGS

Figure **1** is a schematic diagram showing a structure of a display device according to a first example of the present invention;

Figures **2A** to **2D** are schematic views showing examples of arrangements of LEDs included in one light-emitting

block;

Figure **3** is a schematic view showing a specific structure of the display device according to the first example of the present invention;

Figure **4** is a CIE chromaticity diagram showing a color production region of a display device according to the present invention;

Figure **5** is a schematic diagram showing circuits included in a display device according to a second example of the present invention;

Figure **6** is a CIE chromaticity diagram showing a color production region of the display device according to the second example of the present invention;

Figure **7** is a CIE chromaticity diagram showing a change in a color production region when there is a variation in a color produced by a blue-green LED **BG**;

Figures **8A** and **8B** are schematic views showing circuits included in a display device according to a third example;

Figure **9** is a CIE chromaticity diagram showing a color production region of the display device according to the third example of the present invention;

Figure **10** is a CIE chromaticity diagram showing a change in a color production region when there is a variation in a color produced by a blue-green LED **BG**; and

Figure **11** is a CIE chromaticity diagram showing a color production region of a display device according to a fourth example of the present invention.

DESCRIPTION OF THE PREFERRED EMBODIMENTS

Terms and notations used in the description of examples of the present invention are defined as follows.

A "basic color" refers to a color of light emitted from a light-emitting element which is a minimum unit of a display device. Specifically, in the following description of the examples of the present invention, the "basic color" refers to a color of light emitted from an LED. The "basic colors" are represented by notations. For example, $\mathbf{R_{LED}}$ is a color of light emitted from a red LED, and $\mathbf{R_{CRT}}$ is a red color displayed by one pixel of a CRT. Similar notations are used for representing other basic colors.

A "color production region" refers to a range of colors produced by a display device when illustrated on a CIE chromaticity diagram.

A "reference color" is a color that defines the "color production region" of the display device. A "reference color" may be the same as a "basic color" (i.e., a "reference color" may have the same chromaticity coordinates as those of a "basic color") or may be a "color" that is obtained by combining at least two "basic colors". The "reference color" is represented by a notation in which a letter representing a color is accompanied by a subscript "REF" (e.g., $\mathbf{R_{REF}}$).

Hereinafter, the present invention will be described by way of illustrative examples with reference to the accompanying drawings.

(Example 1)

Figure **1** is a schematic diagram showing a structure of an LED display device according to a first example of the present invention. The LED display device according to the first example of the present invention includes: an input processor **1** for receiving a control signal and **RGB** data ($\mathbf{R_{CRT}}$, $\mathbf{G_{CRT}}$ and $\mathbf{B_{CRT}}$) (the input data are the same as the conventional input data); a color arithmetic circuit **2** for converting the **RGB** data received by the input processor **1** into data corresponding to four colors, namely, red ($\mathbf{R_{LED}}$), blue ($\mathbf{B_{LED}}$), yellow-green ($\mathbf{YG_{LED}}$) and blue-green ($\mathbf{BG_{LED}}$); an ON/OFF controller 3 for controlling ON/OFF states of each LED included in each light-emitting block **5** (each dot); and a display circuit **4** in which the light-emitting blocks **5** are arranged along a x-direction and a y-direction so as to form a matrix.

In each light-emitting block **5**, LEDs are arranged, for example, in a form of a 3 x 3 lattice as shown in Figure **2A** in a point symmetric manner where a blue-green LED **BG** is placed at the center. In Figure **2A**, **R**, **B**, **YG** and **BG** each represent types of the LEDs. According to the first example, in order to enhance the color reproducibility in the green

region, yellow-green LEDs **YG**s are arranged at the four corners so as to surround the blue-green LED **BG**.

Figure **3** is a schematic diagram showing a specific structure of the LED display device according to the first example of the present invention shown in Figure **1**. The input processor **1** includes a timing controller **11**, a red data receiving circuit **12**, a green data receiving circuit **13** and a blue data receiving circuit **14**. The timing controller **11** controls the timing of the ON/OFF states of each LED in accordance with an input control signal. The red data receiving circuit **12**, the green data receiving circuit **13** and the blue data receiving circuit **14** receive **R** data, **G** data and **B** data, respectively. In other words, the input processor **1** has a three-unit structure corresponding to the **RGB** data.

The color arithmetic circuit **2** includes a color comparator **21**, a red data processor **22**, a blue-green data processor **23**, a yellow-green data processor **24** and a blue data processor **25**. The color comparator **21** converts **RGB** data received by the input processor **1** into data representing a combination ratio of four colors which are to be produced by the LEDs, i.e., R_{LED}, B_{LED}, YG_{LED} and BG_{LED} (i.e., an emission intensity ratio of the four LEDs). The red data processor **22**, the blue-green data processor **23**, the yellow-green data processor **24** and the blue data processor **25** process the converted data corresponding to the four colors, respectively. In other words, the color arithmetic circuit **2** has a four-unit structure corresponding to the converted data representing the four colors (i.e., four basic colors).

The ON/OFF controller **3** includes a red data array converter **31**, a blue-green data array converter **32**, a yellow-green data array converter **33** and a blue data array converter **34**. The ON/OFF controller **3** further includes a switching circuit **35** for the red LED, a switching circuit **36** for the blue-green LED, a switching circuit **37** for the yellow-green LED and a switching circuit **38** for the blue LED. The four data array converters **31** to **34** convert the paralleled data of four colors obtained by the color arithmetic circuit **2** into series-strung data, respectively. Moreover, the four LED switching circuits **35** to **38** switch the red LED **R**, the blue-green LED **BG**, the yellow-green LED **YG** and the blue LED **B** to an ON state based on each of the serial-strung data representing the four colors after controlling the level of each LED. Thus, the ON/OFF controller **3** has a four-unit structure corresponding to the converted data of the four basic colors.

A switching element **Tr** of the display circuit **4** connected with each LED is switched ON/OFF by the output from the timing controller **11**, thereby controlling the light-emitting time for each period of each LED.

When data corresponding to the basic colors (RGB data) are input into the LED display device having the above-described structure in the same manner as in the case of the conventional LED display device, a display with excellent color reproducibility can be obtained in the green color region by the light-emitting LEDs of the four colors (R_{LED}, B_{LED}, YG_{LED} and BG_{LED}) in the light-emitting blocks **5**.

Hereinafter, the color reproducibility of the LED display device will be described with reference to Figure **4**. Figure **4** is a chromaticity diagram where all colors can be expressed within a curved region. Each color is specified by coordinates with respect to the vertical and horizontal axes of the chromaticity diagram.

A point W_{REF} shown at the center of the curved region represents a white color. A region to the right of the point W_{REF} is a red color region. A region to the upper left of the point W_{REF} is a green color region and a region to the lower left to the point W_{REF} is a blue color region.

Since a conventional light-emitting block or an LED display device with conventional light-emitting blocks consists of red, blue and yellow-green LEDs as described above, colors are produced only within a triangle region having vertices at R_{LED}, B_{LED} and YG_{LED} in Figure **4**. An NTSC (National Television System Committee) system television can produce colors within a triangle region having its vertices at R_{CRT}, G_{CRT} and B_{CRT}.

Therefore, the conventional light-emitting block is considered inferior to the NTSC system television in color reproducibility for a triangle region having its vertices at YG_{LED}, B_{LED} and G_{CRT}. In other words, the conventional light-emitting block has a large area in the green region where it is impossible to produce color.

The light-emitting block **5** in the LED display device according to the present invention is provided with the red LED, the blue LED, the yellow-green LED and the blue-green LED. As a result, the light-emitting block **5** can display colors within a square region having vertices at R_{LED}, B_{LED}, BG_{LED} and YG_{LED}.

When the light-emitting block **5** is compared to the conventional light-emitting block, the possible display region (on the chromaticity diagram) is expanded for a triangle region having its vertices at YG_{LED}, BG_{LED} and B_{LED}, thereby enhancing color reproducibility in green and blue color regions.

Figures **2B** through **2D** show other exemplary structures of a light-emitting block applicable in the present invention. In the case of Figure **2B**, the light-emitting block **5** consists of LEDs corresponding to seven colors, namely, red (**R**), green (**G**), blue (**B**), yellow (**Y**), orange (**O**), purple (**P**) and light blue (**C**). In this case, the color arithmetic circuits **2** and the ON/OFF controllers **3** previously described with reference to Figures **1** and **3** are provided so as to form a seven-unit structure in each light-emitting block.

In a light-emitting block shown in Figure **2C**, a green LED is placed at the center, and LEDs of 6 colors, namely, **Y**, **B**, **W**, **C**, **R** and **P** are placed so as to surround the green LED. The six LEDs and the green LED **G** are equally separated from each other.

A light-emitting block shown in Figure **2D** includes 18 LEDs. The 18 LEDs are formed of LEDs of 8 colors, namely, **G, P, B, Y, R, YG, W** and **C**.

(Example 2)

Hereinafter, an LED display device according to a second example of the present invention will be described.

As shown in Figure **5**, a circuit section **500** includes an input processor **510**, a color arithmetic circuit **520** and an ON/OFF controller **530**. The input processor **510** receives an input data representing a combination ratio of R_{CRT}, G_{CRT} and B_{CRT} and outputs the input data to the color arithmetic circuit **520**. The color arithmetic circuit **520** converts the input data into a data representing the combination ratio of the four basic colors and outputs the data to the ON/OFF controller **530**. The ON/OFF controller **530** controls ON/OFF states of each of the four light-emitting diodes included in a light-emitting block **5** in accordance with the received output data.

Next, functions and structure of the color arithmetic circuit **520** will be described. The color arithmetic circuit **520** uses four basic colors as four reference colors so as to define a color production region of the light-emitting block. In addition to the four reference colors, a white color represented by **RGB** data having equal ratio (i.e., $\mathbf{R_{CRT}}:\mathbf{G_{CRT}}:\mathbf{B_{CRT}}$ = 1 **:** 1 : 1) is also considered as a reference color $\mathbf{W_{REF}}$. As shown in Figure **6**, the color arithmetic circuit **520** divides the color production region so as to define four regions **I** to **IV** each defined by $\mathbf{W_{REF}}$ and two basic colors. Furthermore, point $\mathbf{W_{REF}}$ itself is also considered as a region, i.e., a region **V**.

The color arithmetic circuit **520** includes five region-arithmetic circuits **540a** to **540e** and a color comparator **521**. The color comparator **521** compares three signals forming the input data. By doing so, the color comparator **521** determines which one of the regions **I** to **V** shown in Figure **6** is a region where a color represented by the input data belongs.

Each of the region-arithmetic circuits **540a** to **540e** is formed so as to correspond to each of the regions **I** to **V**, respectively. Each of the region-arithmetic circuits **540a** to **540e** stores formulae for converting the RGB signals (the input data) into a data representing a combination ratio of the four basic colors. The region-arithmetic circuits **540a** to **540e** provide an output data for the four basic colors based on the formulae. These formulae are determined for each of the regions **I** to **V**.

Hereinafter, an example of operations performed by the color comparator circuit **521** and the region-arithmetic circuits **540a** to **540e** will be described. In the case where the color comparator **521** determines that a color represented by an input data belongs to region **I**, the color comparator **521** selects and activates the region-arithmetic circuit **540a** corresponding to region **I**. Then, the region-arithmetic circuit **540a** converts the input data from the input processor **510**, which represents a first color element, a second color element and a third color element (i.e., $\mathbf{R_{CRT}}$, $\mathbf{G_{CRT}}$ and $\mathbf{B_{CRT}}$) into an output data representing a combination ratio of four basic colors, namely, $\mathbf{R_{LED}}$, $\mathbf{BG_{LED}}$, $\mathbf{YG_{LED}}$ and $\mathbf{B_{LED}}$. Although the $\mathbf{R_{CRT}}$ signal, the $\mathbf{G_{CRT}}$ signal and $\mathbf{B_{CRT}}$ signal are input to all of the region-arithmetic circuits **540a** to **540e**, it is only the region-arithmetic circuit **540a** selected by the color comparator **521** that performs the calculation.

As shown in Figure 6, $\mathbf{YG_{LED}}$ lies between $\mathbf{R_{CRT}}$ and $\mathbf{G_{CRT}}$, and $\mathbf{BG_{LED}}$ lies between $\mathbf{G_{CRT}}$ and $\mathbf{B_{CRT}}$. $\mathbf{YG_{LED}}$ is assigned to a particular intermediate color (represented by a particular balance of the value of the input RGB signals) between $\mathbf{R_{CRT}}$ and $\mathbf{G_{CRT}}$ in Figure **6**. Similarly, $\mathbf{BG_{LED}}$ is assigned to a particular intermediate color between $\mathbf{G_{CRT}}$ and $\mathbf{B_{CRT}}$ in Figure **6**. Accordingly, when a data representing either one of the above-mentioned particular intermediate colors is input to the color arithmetic circuit **520**, the color arithmetic circuit **520** outputs an output data such that only the assigned $\mathbf{YG_{LED}}$ or $\mathbf{BG_{LED}}$ are produced. Moreover, a combination ratio of the four basic colors (i.e., an emission intensity ratio of the four LEDs) for producing $\mathbf{G_{CRT}}$ is also assigned by a particular input data.

The output data from the color arithmetic circuit **520** is sent to four output circuits **550a** to **550d** each of which corresponding to $\mathbf{R_{LED}}$, $\mathbf{BG_{LED}}$, $\mathbf{YG_{LED}}$ and $\mathbf{B_{LED}}$, respectively. The output data from the output circuit **550a** to **550d** are, thereafter, input to an output timing circuit **560**. The output timing circuit **560** converts the output data into a signal form for operating the LED display device and outputs the signal to each of the LEDs, thereby controlling the ON/OFF of the four LEDs.

The region-arithmetic circuits **540a** to **540e** have a red data arithmetic circuit **22**, a blue-green data arithmetic circuit **23**, a yellow-green data arithmetic circuit **24** and a blue data arithmetic circuit **25** shown in Figure **3**.

Accordingly, when input signals representing each color of a sequence of colors $\mathbf{R_{CRT}}$-$\mathbf{G_{CRT}}$-$\mathbf{B_{CRT}}$-$\mathbf{R_{CRT}}$ are input to the circuit section **500** having the above-described structure in this order, the four LEDs will sequentially emit light of colors $\mathbf{R_{LED}}$-$\mathbf{YG_{LED}}$-$\mathbf{G_{LED}}$-$\mathbf{BG_{LED}}$-$\mathbf{B_{LED}}$-$\mathbf{R_{LED}}$ in this order. In the case where an input data corresponds to a color that lies between one of LED colors and $\mathbf{W_{REF}}$, the region-arithmetic circuits for each region re-calculates a combination ratio (an emission intensity ratio) of the basic colors based on the combination ratio of $\mathbf{W_{REF}}$ and each of the colors of the four LEDs (i.e., basic colors). Finally, the light-emitting blocks **5** produces a color based on the resultant output signal obtained by re-calculation.

(Example 3)

The display devices according to the first and second examples of the present invention produce colors that may not be obtained in the case of CRT. Such colors may appear unnatural to eyes accustomed to CRT. In the display devices according to the first and second examples of the present invention, each of the region-arithmetic circuits **540a**

to **540e** performs only a certain calculation. Specifically, the region-arithmetic circuits **540a** to **540e** either output a certain data in response to an input data, or produce a color by combining the four colors (the basic colors). Therefore, in the case where colors of the basic colors $\mathbf{R_{LED}}$, $\mathbf{YG_{LED}}$, $\mathbf{BG_{LED}}$ and $\mathbf{B_{LED}}$ are different in different light-emitting blocks **5** due to a variation in LEDs caused during the production process thereof, colors obtained by combining the basic colors $\mathbf{R_{LED}}$, $\mathbf{YG_{LED}}$, $\mathbf{BG_{LED}}$ and $\mathbf{B_{LED}}$ also become different in different light-emitting blocks **5** or display devices. Such an effect is especially significant at the vicinity of boundaries of the color production regions.

Such an effect will be described taking a blue-green LED **BG** as an example. As shown in Figure **7**, when an LED **BG1** which produces a color at a position (represented by chromaticity coordinates) ① is replaced by a different LED **BG2** which produces a color at a position ②, the color production region of the light-emitting block changes from a region having vertices at points $\mathbf{R_{LED}}$, $\mathbf{YG_{LED}}$, ① and $\mathbf{B_{LED}}$ to a region having vertices at points $\mathbf{R_{LED}}$, $\mathbf{YG_{LED}}$, ② and $\mathbf{B_{LED}}$. Such a replacement causes a region having vertices at points ②, ③ and $\mathbf{YG_{LED}}$ to be included in the color production region but causes a region having vertices at points ①, ③ and $\mathbf{B_{LED}}$ to be excluded. Accordingly, each of display devices incorporating the LED **BG1** or the LED **BG2** will produce different colors from each other especially in the vicinity of the basic colors ① and ②. The above-described effect may equally apply to the cases of LEDs of other colors. In such a manner, different colors may be produced in different display devices even in the case where same signals are input thereto.

A circuit section **900** shown in Figure **8A** can exhibit a color production region close to that exhibited by a CRT and at the same time suppress a variation in colors produced by different LEDs. The circuit section **900** has four different LEDs similar to those described in the second example. The circuit section **900** is different from the circuit section **500** in that a color arithmetic circuit **920** uses seven reference colors that are different from the four basic colors.

The circuit section **900** includes an input processor **910**, a color arithmetic circuit **920** and an ON/OFF controller **930**. The input processor **910** receives an input data representing a combination ratio of $\mathbf{R_{CRT}}$, $\mathbf{G_{CRT}}$ and $\mathbf{B_{CRT}}$ and outputs the input data to the color arithmetic circuit **920**. The color arithmetic circuit **920** converts the input data into an output data representing a combination ratio of four basic colors and outputs the output data to the ON/OFF controller **930**. The ON/OFF-controller **930** controls ON/OFF states of each of the four LEDs included in the light-emitting block **5** based on the received output data.

The color arithmetic circuit **920** determines seven reference colors by combining the four basic colors. Specifically, as shown in a chromaticity diagram in Figure **9**, these seven reference colors are $\mathbf{R_{REF}}$ (red), $\mathbf{Y_{REF}}$ (yellow), $\mathbf{G_{REF}}$ (green), $\mathbf{C_{REF}}$ (light blue), $\mathbf{B_{REF}}$ (blue), $\mathbf{P_{REF}}$ (purple) and $\mathbf{W_{REF}}$ (white). These seven reference colors are similar to colors exhibited by a CRT which are visually favorable colors. The color arithmetic circuit **920** uses these seven reference colors so as to define a color production region of the light-emitting block **5**. Moreover, as shown in Figure **9**, the color arithmetic circuit **920** divides the color production region so as to define six regions **I** to **VI** each defined by $\mathbf{W_{REF}}$ and two reference colors other than $\mathbf{W_{REF}}$ Furthermore, point $\mathbf{W_{REF}}$ itself is also considered as one region, i.e., a region **VII**.

The structure and the function of the color arithmetic circuit **920** will be described in more detail. The color arithmetic circuit **920** includes seven region-arithmetic circuits **940a** to **940g** and a color comparator **921**. The color comparator **921** compares three signals forming the input data. By doing so, the color comparator **921** determines which one of the regions **I** to **VII** shown in the chromaticity diagram in Figure **9** is a region where a color represented by the input data belongs.

Each of the region-arithmetic circuits **940a** to **940g** is formed so as to correspond to each of the regions **I** to **VII**, respectively. Each of the region-arithmetic circuits **940a** to **940g** stores a unique data representing a combination ratio of the four basic colors (i.e., an emission intensity ratio of the four LEDs), namely, $\mathbf{R_{LED}}$, $\mathbf{YG_{LED}}$, $\mathbf{BG_{LED}}$ and $\mathbf{B_{LED}}$ for exhibiting the seven reference colors. Each of the region-arithmetic circuits **940a** to **940g** further stores formulae for converting the input data, based on the reference colors, into a data representing a combination ratio of the four basic colors. The region-arithmetic circuits **940a** to **940g** provide an output data for the four basic colors based on the formulae. These formulae are determined for each of the regions **I** to **VII**.

As shown in Figure **8B**, each of the region-arithmetic circuits **940a** to **940g** includes a red signal arithmetic circuit **22**, a blue-green signal arithmetic circuit **23**, a yellow-green signal arithmetic circuit **24** and a blue signal arithmetic circuit **25** shown in Figure **3**.

Input data representing $\mathbf{R_{CRT}}$, $\mathbf{G_{CRT}}$ and $\mathbf{B_{CRT}}$ are converted into output data representing a combination ratio of $\mathbf{R_{REF}}$, $\mathbf{YG_{REF}}$, $\mathbf{BG_{REF}}$ and $\mathbf{B_{REF}}$ as follows. When the input data represents a monochromatic red color ($\mathbf{R_{CRT}}$), one of the region-arithmetic circuits performs a calculation such that a light-emitting block **5** exhibits a color represented by a point lying on a line extending between the reference color $\mathbf{W_{REF}}$ and the reference color $\mathbf{R_{REF}}$ By similar calculation, when the input data represents a monochromatic green color ($\mathbf{G_{CRT}}$), the light-emitting block **5** exhibits a color represented by a point lying on a line between the reference color $\mathbf{W_{REF}}$ and the reference color $\mathbf{G_{REF}}$. When the input data represent a monochromatic blue color ($\mathbf{B_{CRT}}$), the light-emitting block exhibits a color represented by a point lying on a line extending between the reference color $\mathbf{W_{REF}}$ and the reference color $\mathbf{B_{REF}}$ In the case where the input data represents $\mathbf{R_{CRT}}$:$\mathbf{G_{CRT}}$ = 1 : 1, one of the region-arithmetic circuits performs calculation such that the light-emitting block **5**

exhibits a color represented by a point lying on a line extending between the reference color $\mathbf{W_{REF}}$ and the reference color $\mathbf{Y_{REF}}$. Similarly, when the input data represents $\mathbf{G_{CRT}}$:$\mathbf{B_{CRT}}$ = 1 : 1, the light-emitting block exhibits a color represented by a point lying on a line extending between the reference color $\mathbf{W_{REF}}$ and the reference color $\mathbf{C_{REF}}$. Furthermore, when the input data represents $\mathbf{R_{CRT}}$:$\mathbf{G_{CRT}}$:$\mathbf{B_{CRT}}$ = 1 : 1 : 1, the light-emitting block exhibits a color at point $\mathbf{W_{REF}}$.

Hereinafter, an example of calculation performed by the color arithmetic circuit **920** used in the present example will be described. The emission intensity of each of the four LEDs for producing a color represented by an input data can be calculated by the following formulae.

IR, IG and IB each refer to a signal input to the color arithmetic circuit **920**, and LR, LYG, LBG and LB each refer to a signal output from a converter. The color comparator **921** determines the relative magnitude of values represented by the input signals IR, IG and IB, and determines which one of the regions **I** to **VII** is a region where as a region where the color represented by the input RGB signals belongs, based on a conversion table shown in Table 1.

Table 1

Region	Determination		
	IR-IG	IG-IB	IB-IR
I	≧0	≧0	---
II	---	≧0	---
III	---	≧0	≧0
IV	---	---	≧0
V	≧0	---	≧0
VI	≧0	---	---
VII	0	0	0
---: No determination			

The combination ratios of the basic colors (i.e., the emission intensity ratio of the four LEDs) for exhibiting the seven reference colors are shown in Table 2.

Table 2

Reference color	R_{LED}	YG_{LED}	BG_{LED}	B_{LED}
R_{REF}	Rr	Ryg	Rbg	Rb
Y_{REF}	Yr	Yyg	Ybg	Yb
G_{REF}	Gr	Gyg	Gbg	Gb
C_{REF}	Cr	Cyg	Cbg	Cb
B_{REF}	Br	Byg	Bbg	Bb
M_{REF}	Mr	Myg	Mbg	Mb
W_{REF}	Wr	Wyg	Wbg	Wb

Arithmetic formulae of regions **I** to **VII** for obtaining the output signals are shown as Formulae (1) to (8), where notations X, Y and C1-C3 are substituted with variables shown in Table 3.

•Regions **I-VI**

$$LR = (W_r * C1) + (X_r * C2) + (Z_r * C3) \quad (1)$$

$$LYG = (W_{yg} * C1) + (X_{yg} * C2) + (Z_{yg} * C3) \quad (2)$$

$$LBG = (W_{bg} * C1) + (X_{bg} * C2) + (Z_{bg} * C3) \quad (3)$$

$$LB = (W_b * C1) + (X_b * C2) + (Z_b * C3) \quad (4)$$

•Region **VII**

$$LR = W_r * IR \quad (5)$$

$$LYG = W_{yg} * IG \quad (6)$$

$$LBG = W_{bg} * IG \quad (7)$$

$$LB = W_b * IB \quad (8)$$

Table 3

Region	C1	X	C2	Z	C3
I	IB	R	IR-IG	Y	IG-IB
II	IB	G	IG-IR	Y	IR-IB
III	IR	G	IG-IB	C	IB-IR
IV	IR	B	IB-IG	C	IG-IR
V	IG	B	IB-IR	M	IR-IG
VI	IG	R	IR-IB	M	IB-IG

By using the above-described formulation, for example, arithmetic expressions (9) to (12) in region **I** are derived from the above Formulae (1) to (4) and the first line of Table 3 as follows.

$$LR = (W_r * IB) + (R_r * (IR - IG)) + (Y_r * (IG - IB)) \quad (9)$$

$$LYG = (W_{yg} * IB) + (R_{yg} * (IR - IG)) + (Y_{yg} * (IG - IB)) \quad (10)$$

$$LBG = (W_{bg} * IB) + (R_{bg} * (IR - IG)) + (Y_{bg} * (IG - IB)) \quad (11)$$

$$LB = (W_b * IB) + (R_b * (IR - IG)) + (Y_b * (IG - IB)) \quad (12)$$

Moreover, arithmetic formulae (13) to (16) in region **V** are derived from the above formulae (1) to (4) and the fifth line of Table 3 as follows.

$$LR = (W_r * IG) + (B_r * (IB - IR)) + (M_r * (IR - IG)) \quad (13)$$

$$LYG = (W_{yg} * IG) + (B_{yg} * (IB - IR)) + (M_{yg} * (IR - IG)) \quad (14)$$

$$LBG = (W_{bg} * IG) + (B_{bg} * (IB - IR)) + (M_{bg} * (IR - IG)) \quad (15)$$

$$LB = (W_b * IG) + (B_b * (IB - IR)) + (M_b * (IR - IG)) \quad (16)$$

Hereinafter, changes in the colors due to variation in colors of light emitted by LEDs will be described with reference to Figure **10**. A case will be described where a position (represented by chromaticity coordinates) of a color that is exhibited by an LED **BG** is shifted from ① to ② in a like manner as described with reference to Figure **7**. As shown in Figure **10**, such a shift will cause a position of a reference color $\mathbf{G_{REF}}$ (=$\mathbf{G_{CRT}}$) to be shifted to $\mathbf{G1_{REF}}$ and a position of a reference color $\mathbf{Y_{REF}}$ to $\mathbf{Y1_{REF}}$. However, as is apparent from the chromaticity diagram, deviation of the chromaticity coordinates of the reference colors is smaller than that of the chromaticity coordinates of the basic colors.

The above-described shift in the color production position of the LED **BG** causes a region having vertices at points $\mathbf{Y_{REF}}$, $\mathbf{Y1_{REF}}$, $\mathbf{G_{REF}}$ and $\mathbf{G1_{REF}}$ to be included but causes a region having vertices at points $\mathbf{G1_{REF}}$, $\mathbf{G_{REF}}$, $\mathbf{C1_{REF}}$, $\mathbf{B_{REF}}$ and $\mathbf{C_{REF}}$ to be excluded. However, the shift in regions are small enough that they are visually unnoticeable. Similarly,

when there are color variations in the basic colors exhibited by LEDs of other colors, the change in the color production region defined by the seven reference colors is also sufficiently small.

(Example 4)

Figure **11** is a chromaticity diagram representing colors exhibited by a display device according to a fourth example of the present invention in which six LEDs of six colors are used. The six LEDs respectively exhibit six basic colors, namely, R_{LED}, YG_{LED}, G_{LED}, C_{LED}, B_{LED} and P_{LED}.

As shown in Figure **11**, a color production region of a CRT lies within a region defined by the basic colors exhibited by the six LEDs. Thus, the display device according to the fourth example of the present invention can produce colors that are exhibited by the CRT using a light-emitting block **5** having the six LEDs. In order to correspond to the color production characteristics of the CRT, R_{REF2}, Y_{REF2}, G_{REF2}, C_{REF2}, B_{REF2}, P_{REF2} and W_{REF2} are determined on the chromaticity diagram as seven reference colors. These seven reference colors are suitable for reproducing the color production characteristics of the CRT that the color production region defined by these reference colors encloses the color production region of the CRT. The color production in the color production region defined by the seven reference colors may be controlled by storing, in a region-arithmetic circuit, combination ratios of the six basic colors as specific values for producing the seven reference colors.

The display device according to the third example of the present invention which uses four LEDs in one light-emitting block **5** may also be made to exhibit the colors produced by the CRT. This can be realized by setting the data stored in the color arithmetic circuit **920**, that represent the combination ratios of the basic colors for producing the reference colors, to the data representing the combination ratios for producing R_{REF2}, Y_{REF2}, G_{REF2}, C_{REF2}, B_{REF2}, P_{REF2} and W_{REF2}.

The above-described setting is applicable to display devices having any number of basic colors (i.e., any number of LEDs) as long as a region defined by basic colors produced by the LEDs encloses a desired color production region. Accordingly, even two display devices having different LEDs can produce same colors by having colon sets of seven reference colors.

An LED display device according to the present invention can produce light having a color close to a pure green color. Accordingly, color reproducibility in a green color region can be enhanced, thereby realizing a well-balanced color display. Furthermore, the LED display device according to the present invention can exhibit a color production region similar to that of a CRT and at the same time is able to suppress undesirable variations in colors produced by LEDs.

Various other modifications will be apparent to and can be readily made by those skilled in the art without departing from the scope and spirit of this invention. Accordingly, it is not intended that the scope of the claims appended hereto be limited to the description as set forth herein, but rather that the claims be broadly construed.

Claims

1. A display device, comprising:

a light-emitting block including a plurality of light-emitting elements for emitting N number of different basic colors;
an input circuit for receiving an input data representing a first color, a second color and a third color;
a converter for converting the input data into an output data representing N number of basic colors; and
a controller for controlling ON/OFF states of the plurality of light-emitting elements according to the output data, wherein
N is an integer of 4 or higher.

2. A display device according to claim 1, wherein:

a color production region of the light-emitting block on a chromaticity diagram has a plurality of regions defined by M number of reference colors;
each of the M number of reference colors are obtained based on at least one of the N number of basic colors; and
the converter includes a circuit for selecting one of the plurality of regions in accordance with the input data and a circuit for generating the output data based on at least one of the reference colors corresponding to the selected region.

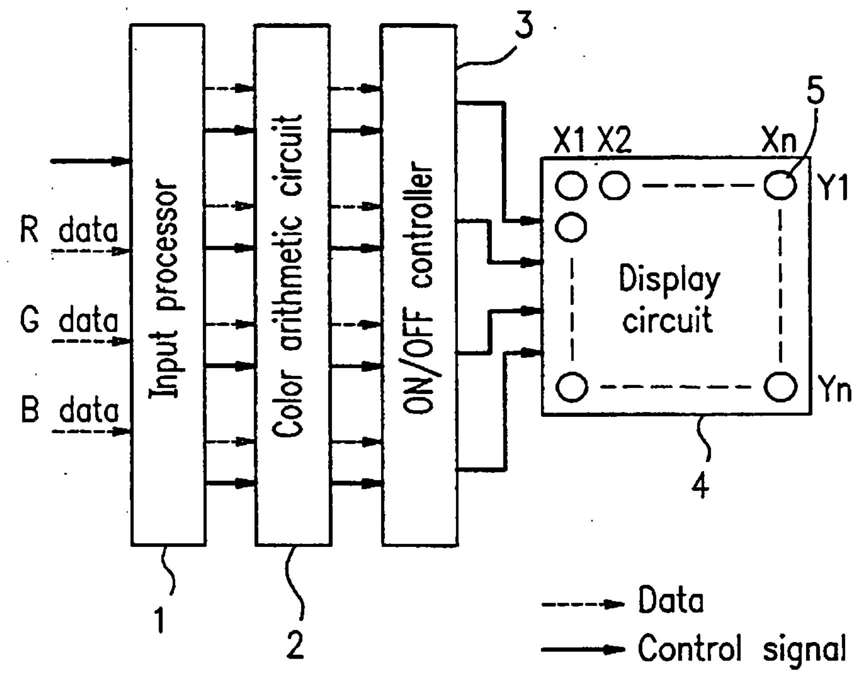
3. A display region according to claim 2, wherein the plurality of regions covers a color production region of a CRT.

4. A display region according to claim 2, wherein at least one of the M number of reference colors is different from the N number of basic colors.

5. A display device according to claim 1, wherein the N number of light-emitting elements are four light-emitting diodes which emit light of the basic colors, namely, red, blue, yellow-green and blue-green, respectively.

6. A display device according to claim 5, wherein M is an integer of 4 or higher.

FIG. 1



3
5
R data
G data
B data
Input processor
Color arithmetic circuit
ON/OFF controller
X1 X2
Xn
Y1
Yn
Display circuit
4
1
2
Data
Control signal

FIG.2A

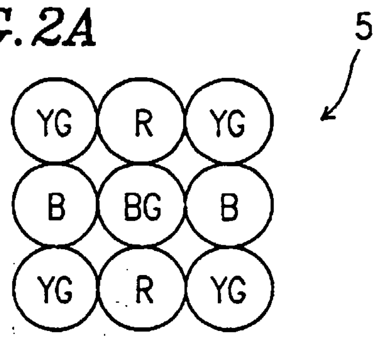


FIG.2B

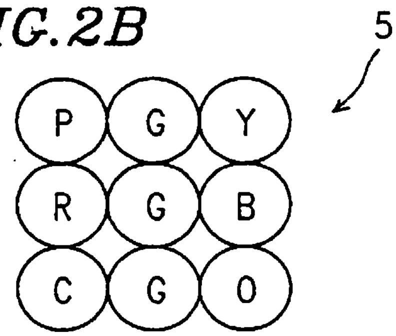


FIG.2C

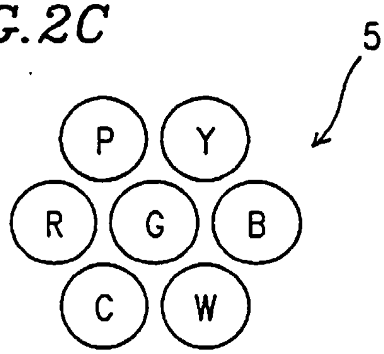


FIG.2D

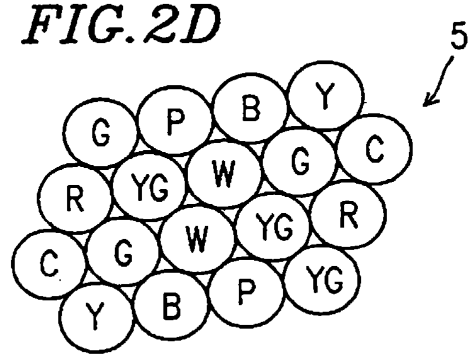


FIG. 3

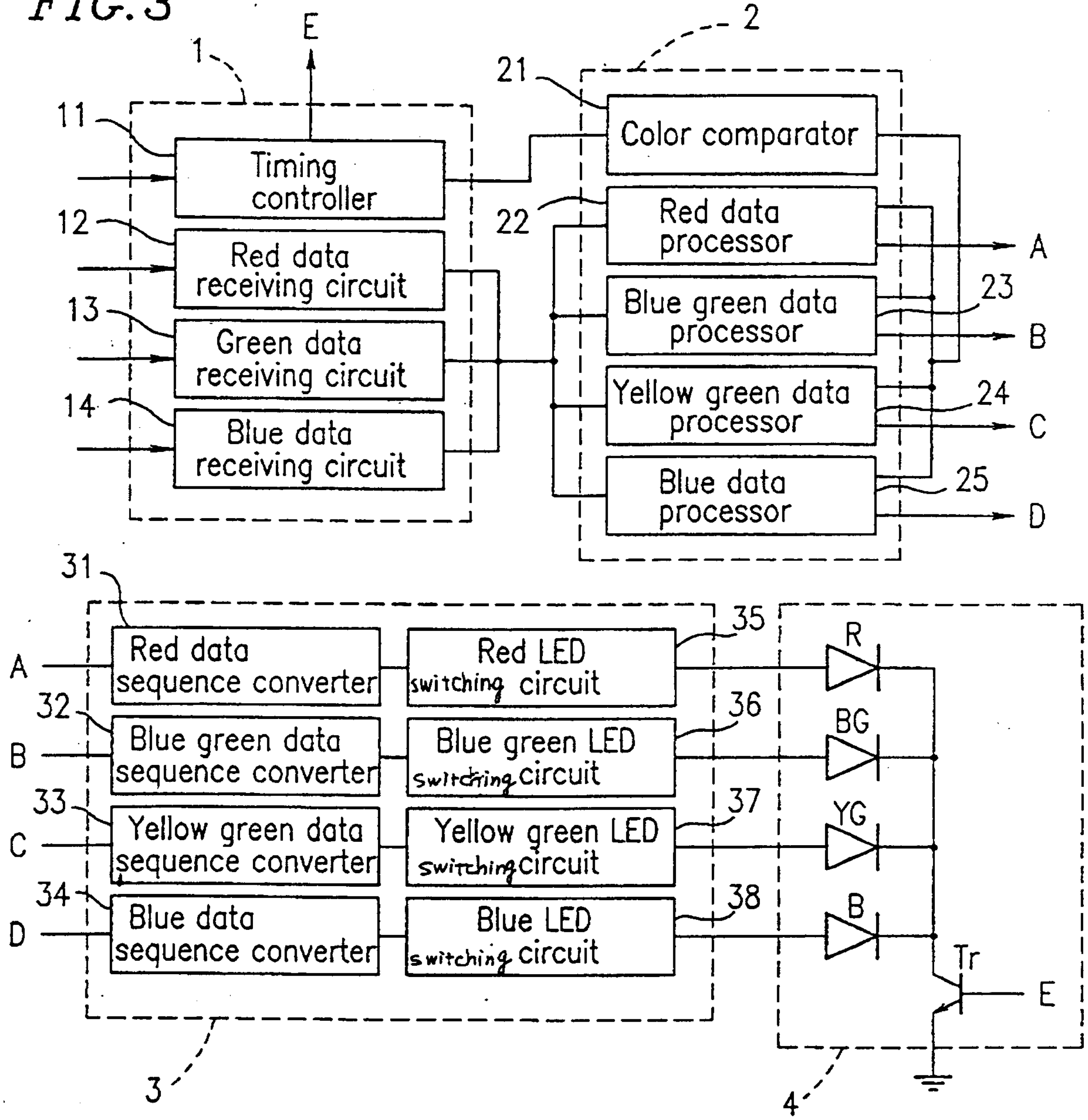

E
1
2
21
11
Timing controller
Color comparator
12
22
Red data receiving circuit
Red data processor
A
13
23
Green data receiving circuit
Blue green data processor
B
14
24
Blue data receiving circuit
Yellow green data processor
C
25
Blue data processor
D
31
35
A
Red data sequence converter
Red LED switching circuit
R
32
36
B
Blue green data sequence converter
Blue green LED switching circuit
BG
33
37
C
Yellow green data sequence converter
Yellow green LED switching circuit
YG
34
38
D
Blue data sequence converter
Blue LED switching circuit
B
Tr
E
3
4

FIG. 4

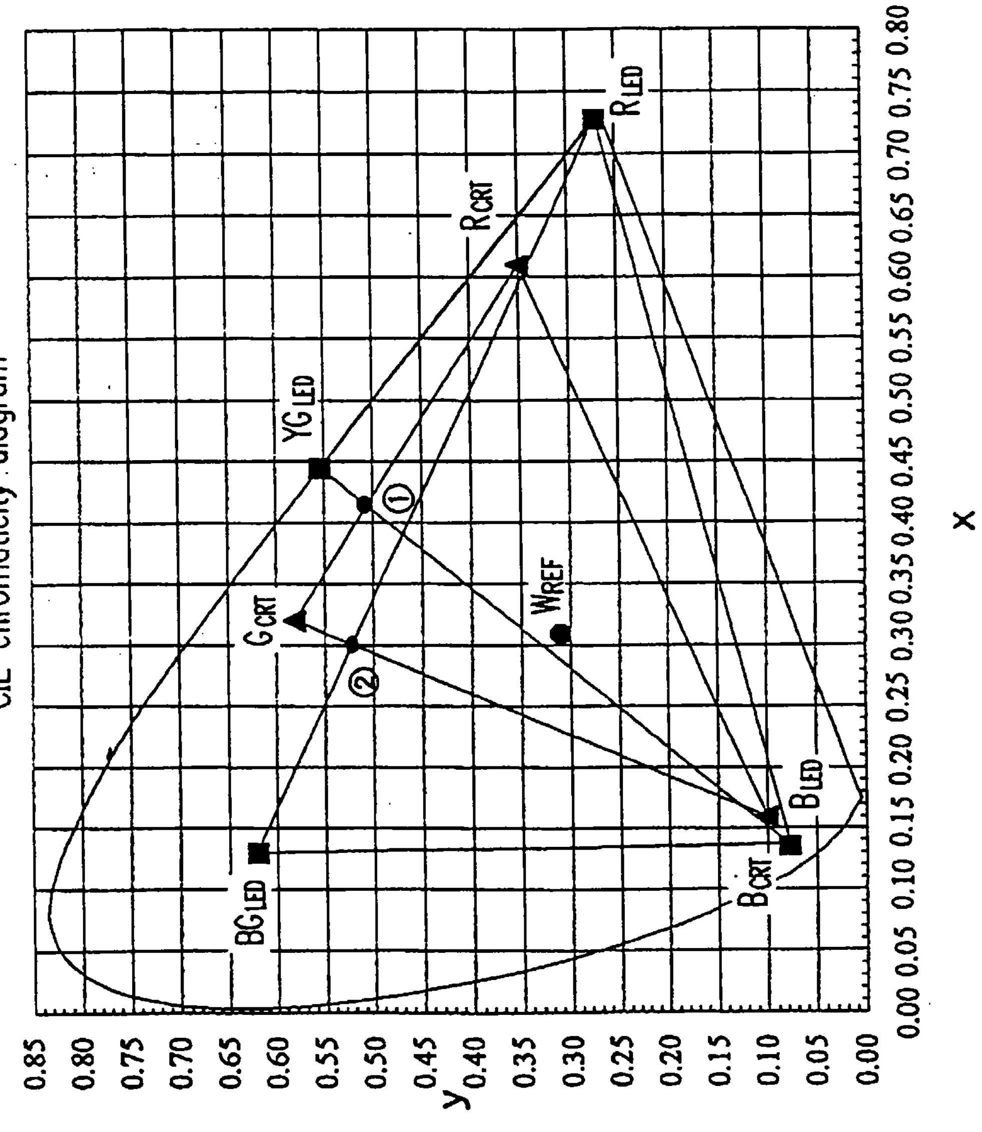

CIE chromaticity diagram
R_{LED}
R_{CRT}
YG_{LED}
G_{CRT}
W_{REF}
BG_{LED}
B_{CRT}
B_{LED}
①
②
x
y
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70 0.75 0.80
0.85 0.80 0.75 0.70 0.65 0.60 0.55 0.50 0.45 0.40 0.35 0.30 0.25 0.20 0.15 0.10 0.05 0.00

FIG.5

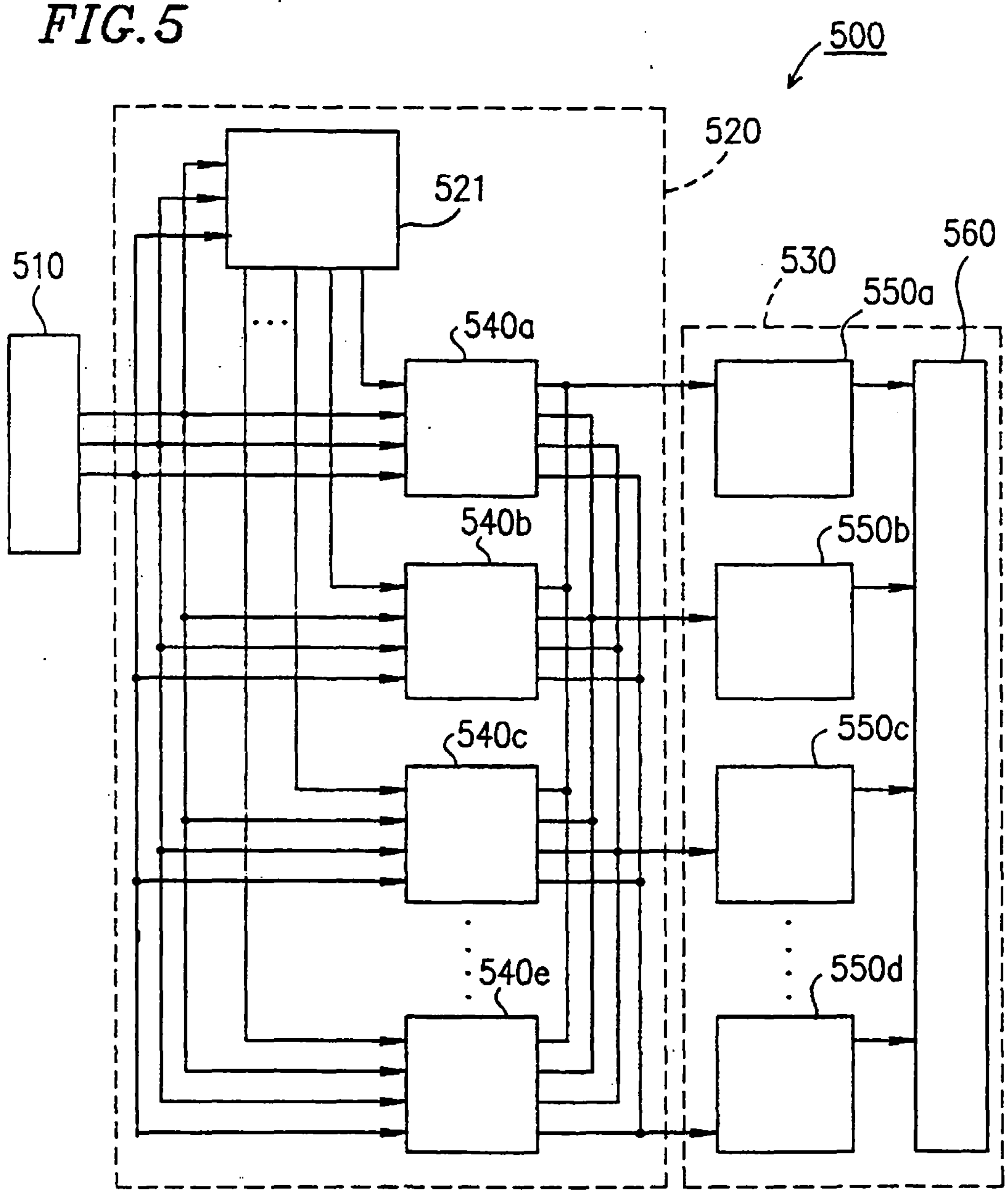

500
520
521
510
530
560
550a
540a
540b
550b
540c
550c
540e
550d

FIG.6

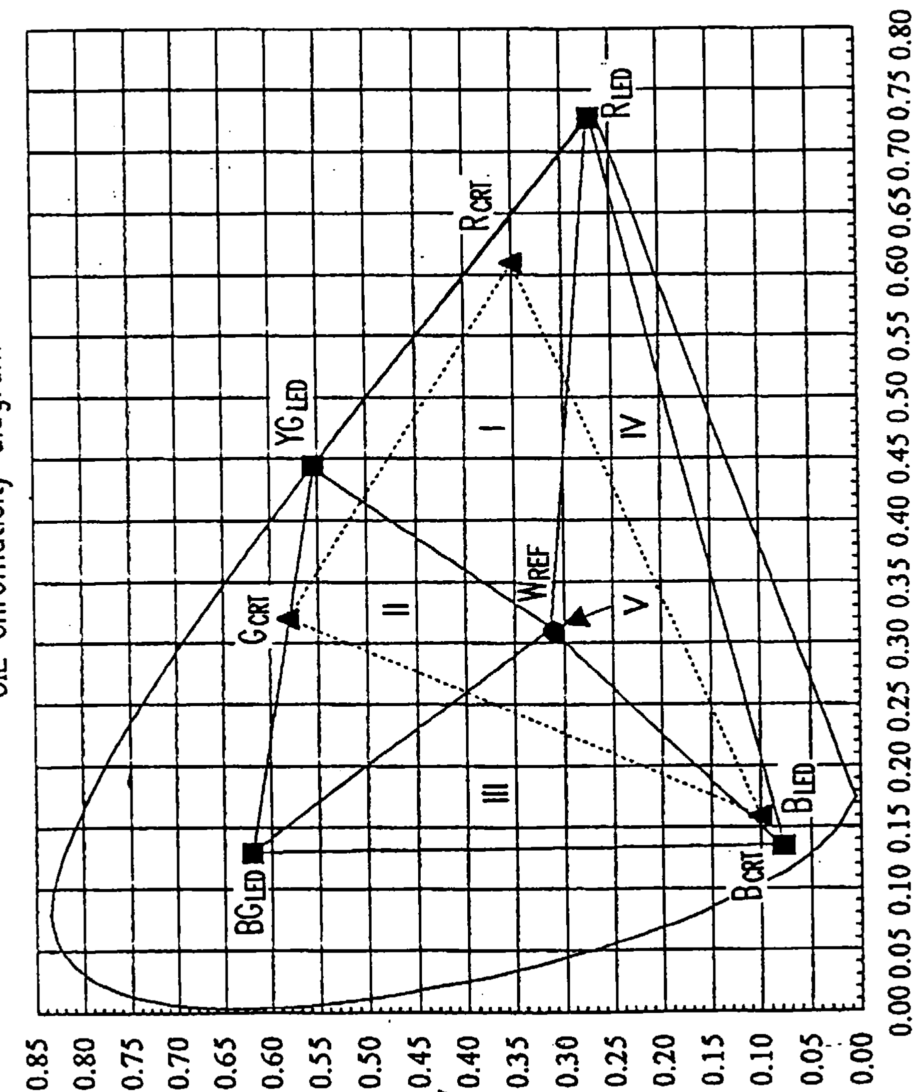

CIE chromaticity diagram
y
x
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70 0.75 0.80
YG_{LED}
BG_{LED}
R_{LED}
B_{LED}
R_{CRT}
G_{CRT}
B_{CRT}
W_{REF}
I
II
III
IV
V

FIG. 7

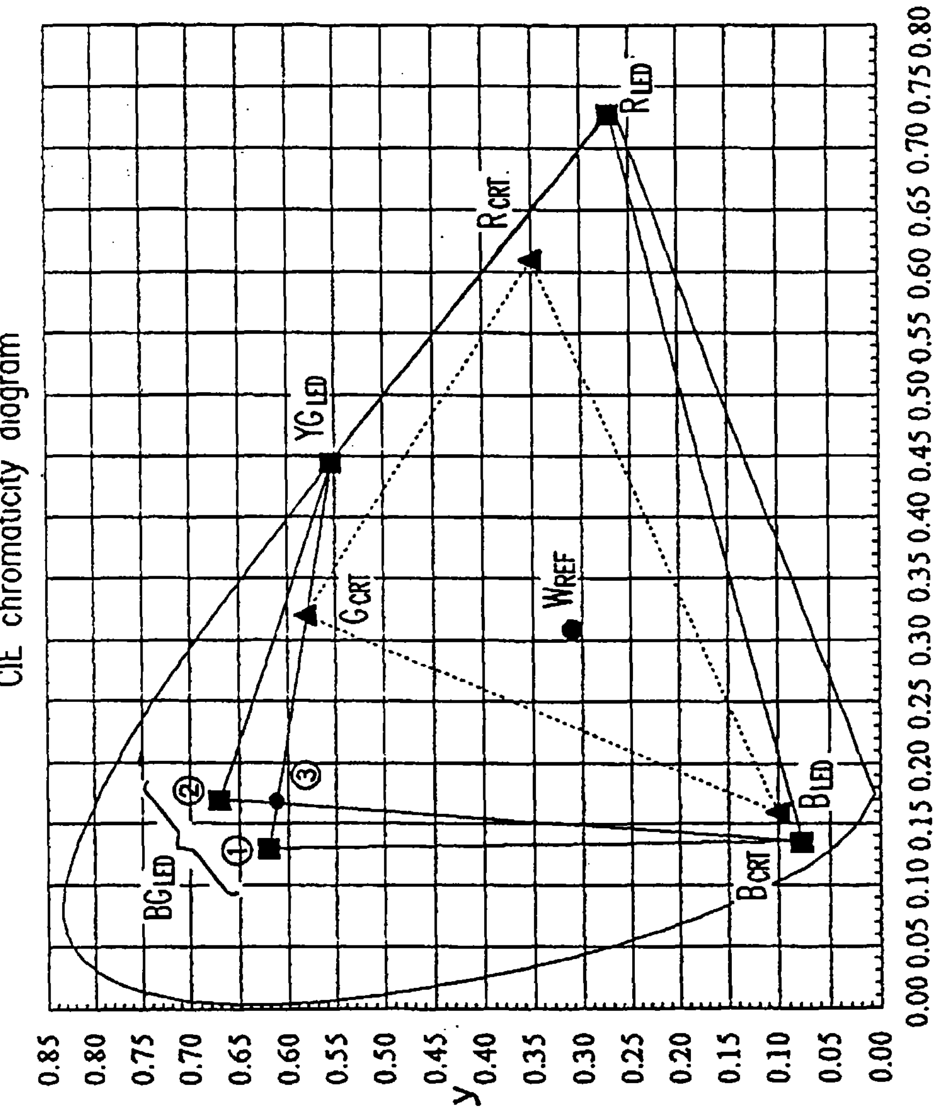

CIE chromaticity diagram
y
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
x
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70 0.75 0.80
R_LED
R_CRT
YG_LED
G_CRT
W_REF
BG_LED
1
2
3
B_LED
B_CRT

FIG. 8A

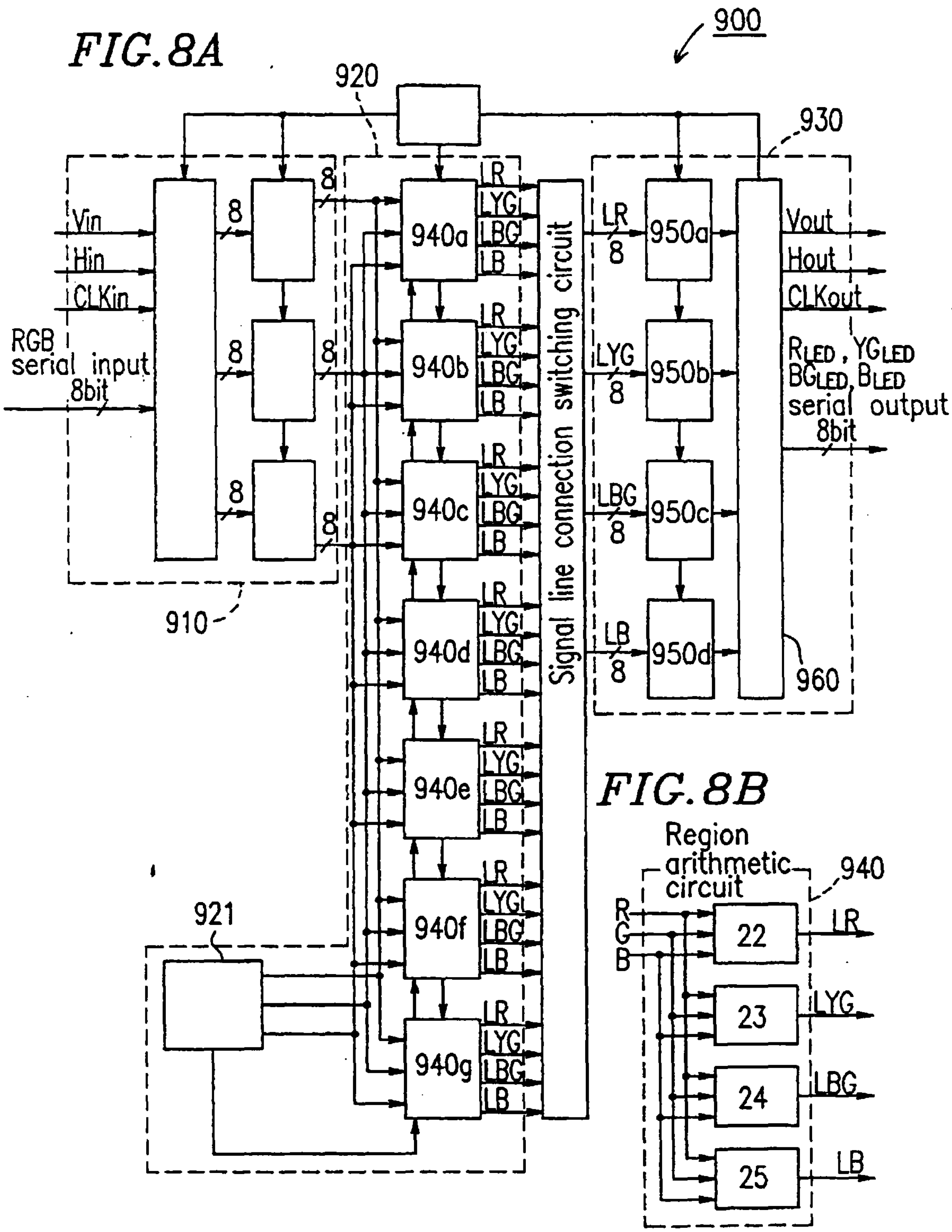

900
920
930
Vin
Hin
CLKin
RGB serial input 8bit
8
940a
940b
940c
940d
940e
940f
940g
LR
LYG
LBG
LB
Signal line connection switching circuit
950a
950b
950c
950d
Vout
Hout
CLKout
RLED, YGLED BGLED, BLED serial output 8bit
910
921
960
FIG. 8B
Region arithmetic circuit
940
R
G
B
22
23
24
25
LR
LYG
LBG
LB

FIG.9

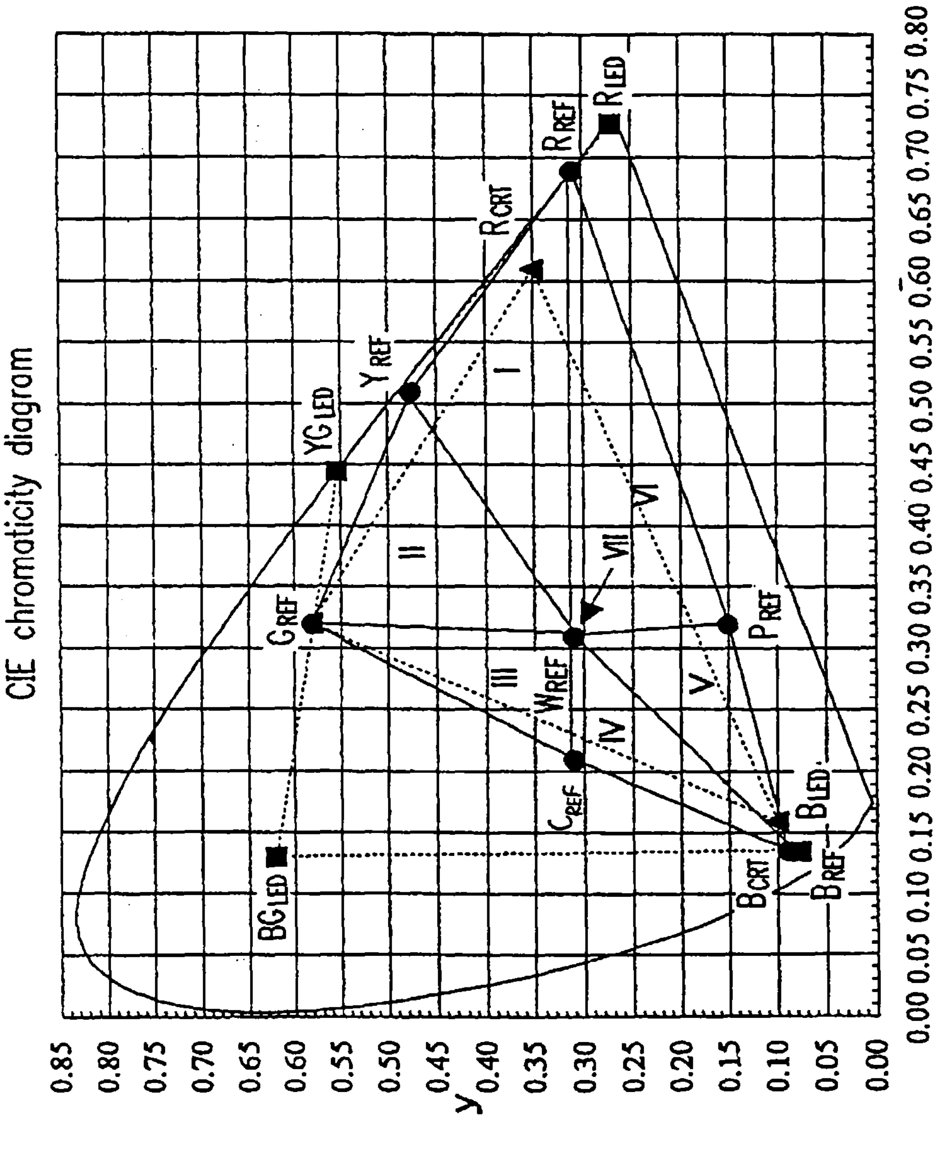

CIE chromaticity diagram
y
0.85
0.80
0.75
0.70
0.65
0.60
0.55
0.50
0.45
0.40
0.35
0.30
0.25
0.20
0.15
0.10
0.05
0.00
x
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70 0.75 0.80
R_LED
R_REF
R_CRT
Y_REF
YG_LED
G_REF
BG_LED
C_REF
W_REF
P_REF
B_LED
B_CRT
B_REF
I
II
III
IV
V
VI
VII

FIG. 10

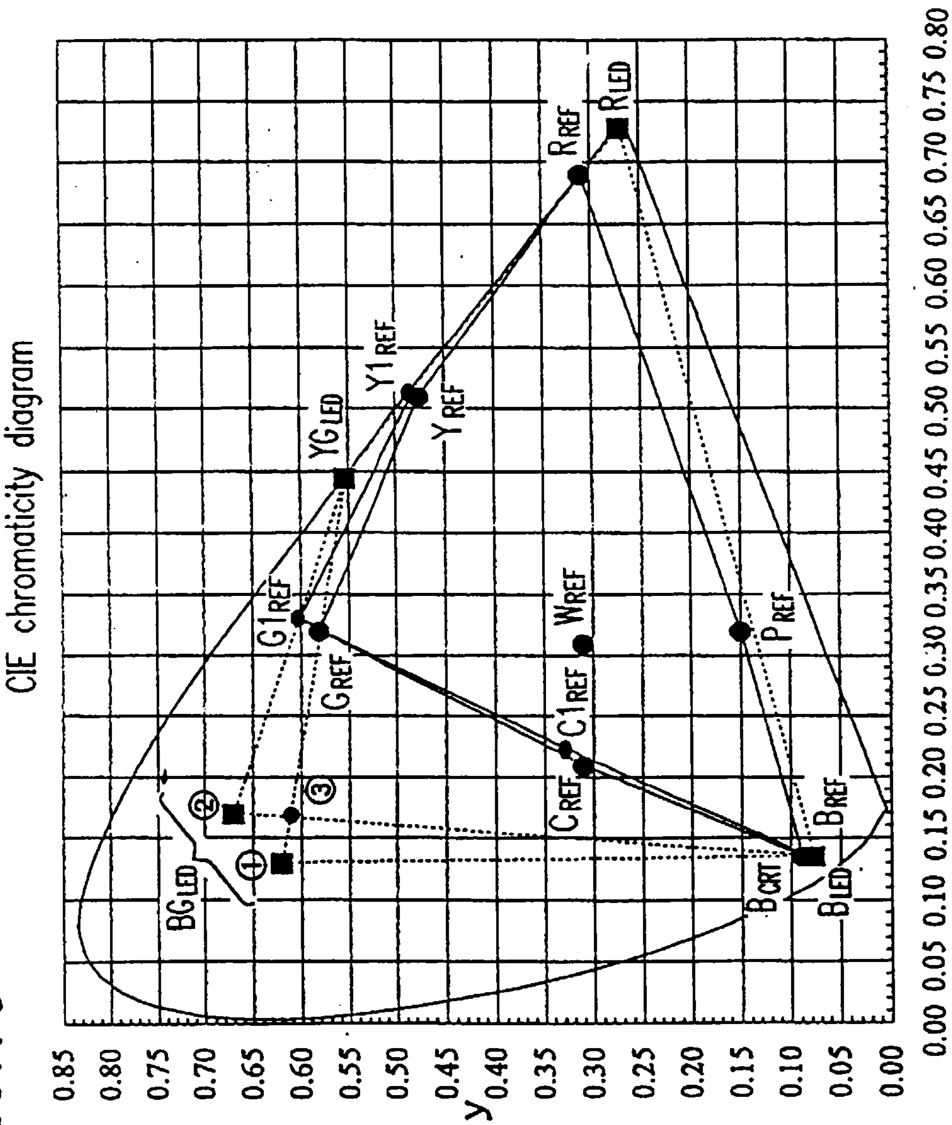
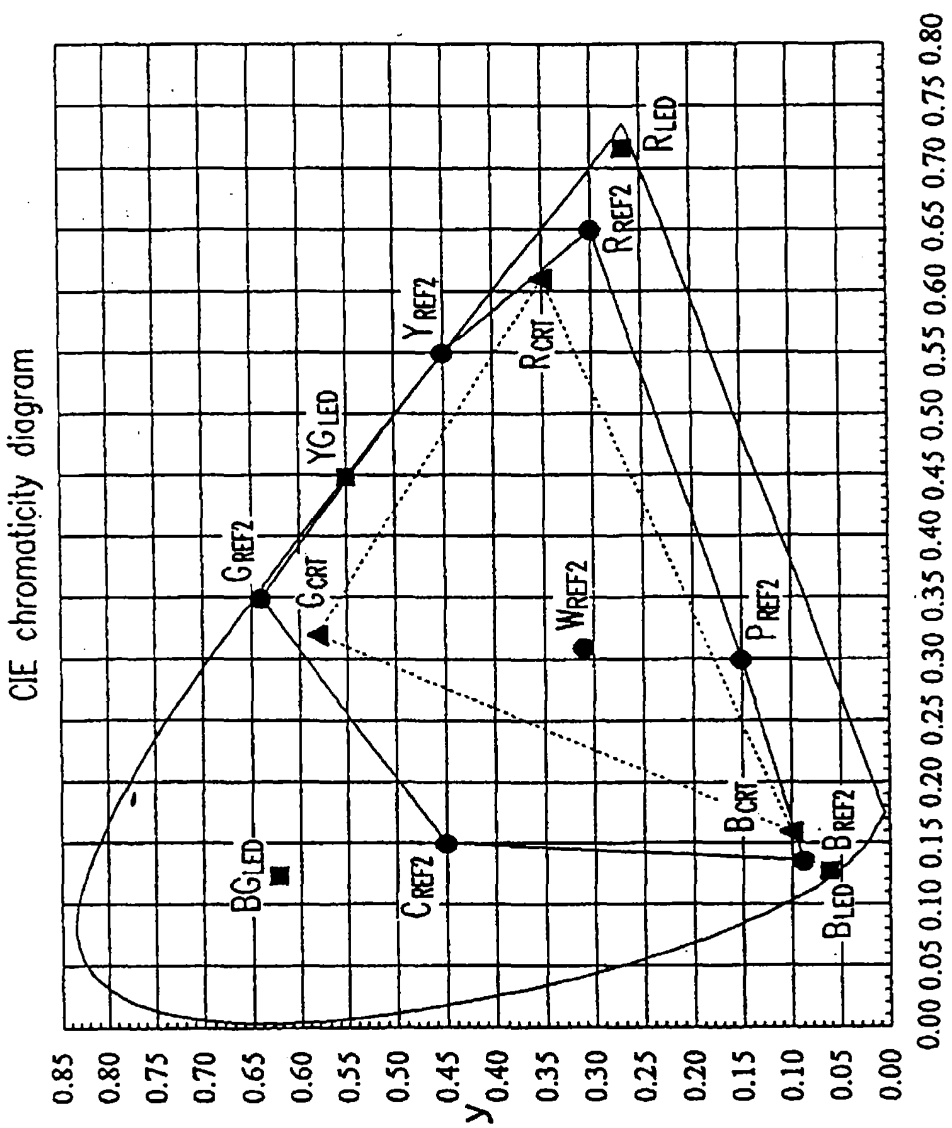

CIE chromaticity diagram
x
y
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70 0.75 0.80
0.85 0.80 0.75 0.70 0.65 0.60 0.55 0.50 0.45 0.40 0.35 0.30 0.25 0.20 0.15 0.10 0.05 0.00
R_{LED}
R_{REF}
$Y1_{REF}$
Y_{REF}
YG_{LED}
$G1_{REF}$
G_{REF}
W_{REF}
$C1_{REF}$
C_{REF}
P_{REF}
B_{REF}
B_{CRT}
B_{LED}
BG_{LED}
①
②
③

FIG. 11


CIE chromaticity diagram
x
y
0.00 0.05 0.10 0.15 0.20 0.25 0.30 0.35 0.40 0.45 0.50 0.55 0.60 0.65 0.70 0.75 0.80
0.85 0.80 0.75 0.70 0.65 0.60 0.55 0.50 0.45 0.40 0.35 0.30 0.25 0.20 0.15 0.10 0.05 0.00
GREF2
GCRT
YGLED
YREF2
RCRT
RREF2
RLED
WREF2
PREF2
BCRT
BREF2
BLED
CREF2
BGLED